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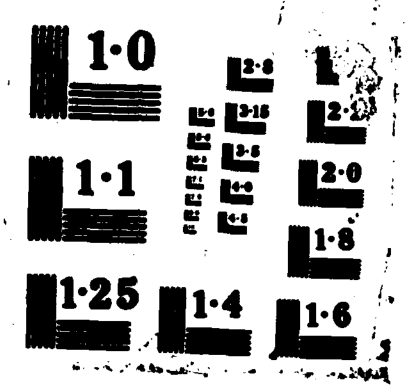
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Distributed Tactical Decision Support is a theoretical investigation being performed by NOSC for ONR to better understand the distributed tactical decision-making process. Real-time tracking for combat direction, using a distributed database system as a support tool, will be used as a baseline for understanding that process. The theory next will be generalized beyond the tracking problem. The purpose of the investigation is to develop mechanisms for maximizing the quality of human decision making and improving its timeliness in such a distributed environment. These improvements can best be attained by the understanding of those critical factors that ensure a consistent display of distributed tactical information at all levels of use.

This investigation is considering the knowledge domain of tracking in a combat direction system, the rules that must apply to that domain when evaluating a possible threat, and the human interaction required. The domain of mission planning at the battle-group level will be considered to compare concerns for timeliness and decision quality. Investigation of the timing and memory constraints that arise when trying to examine why a particular decision was made in either domain also will be performed. Examples of these constraints include the unraveling of the rules that were applied to determine whether a given track was hostile ~~(see Appendices A and B)~~ or the analysis of why a combatant was deployed at a particular time and site during mission planning.

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DISTRIBUTED TACTICAL DECISION SUPPORT*

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BACKGROUND:

Distributed Tactical Decision Support is a theoretical investigation being performed by NOSC for ONR to better understand the distributed tactical decision-making process. Real-time tracking for combat direction, using a distributed database system as a support tool, will be used as a baseline for understanding that process. The theory next will be generalized beyond the tracking problem. The purpose of the investigation is to develop mechanisms for maximizing the quality of human decision making and improving its timeliness in such a distributed environment. These improvements can best be attained by the understanding of those critical factors that ensure a consistent display of distributed tactical information at all levels of use.

This investigation is considering the knowledge domain of tracking in a combat direction system, the rules that must apply to that domain when evaluating a possible threat, and the human interaction required. The domain of mission planning at the battle-group level will be considered to compare concerns for timeliness and decision quality. Investigation of the timing and memory constraints that arise when trying to examine why a particular decision was made in either domain also will be performed. Examples of these constraints include the unraveling of the rules that were applied to determine whether a given track was hostile (see Appendices A and B) or the analysis of why a combatant was deployed at a particular time and site during mission planning.

The tracking model is based on the birth/death of a contact or object, whose value is designated as a track number, together with time of entry into the Combat Direction System (CDS). The model captures, via transactions, different views or opinions of information on the contact as it is being processed by the various actions of the CDS. Time 0 (T0) is designated as the time when the sensor gains contact and the track is formed. The "death" of the contact could occur because of loss of sensor contact, because of contact engagement, or because of reassessment as a contact with a different value. Between "birth and death" occur a number of steps or actions required to determine the identity and location of the contact. In each case, severe real-time constraints must be met.

In the framework of the model, dynamic contact information consisting of tracking data will be input into a centralized computer database and broadcast to the CDS operator consoles for intelligent machine-based analysis; i.e., for Remote/Radar/Electronic Support Measures (ESM) console(s) and Area Sector console(s). A console's view of its tracks can be inconsistent with another console's view of those tracks. These views can become consistent for a number of different reasons, while still obeying the rules of operation established when the consoles are operating independently. The time, amount of communication required, track quality (or confidence level), number of operators involved in achieving a consistent consensus view of the track, and assessment of risk in assuming that concensus will be analyzed. The results will be compared to achieving that view by using a centralized database and traditional statistical correlation techniques [Ref. 1].

Relative performance measurements for timeliness and information confidence are being gathered by means of a NOSC-distributed tracking model testbed (see Figure 1) configured of three SUN 3/50Ms, each supported by a hard-disk drive, providing the Berkeley 4.2BSD distributed version of UNIX and interconnected via Ethernet. These measurements will show the advantages/disadvantages of distributed decision making in the tracking of detected contacts. The hypothesis to be tested is that of showing that more responsive decisions can be made with better quality (more confidence) than today's centralized systems provide.

THEORETICAL APPROACH:

The method used in this investigation includes optimizing the querying of the database (see Figure 2 and Ref. 2) in support of the real-time distributed tracking problem. Machine-based reasoning will be used to determine why a particular query should or should not be accomplished. An example would be a comparison of platform track speed versus maximum air contact speeds in the database to assess what the threat could or could not be (i.e., not a helicopter because its speed is too great), or to establish how quick the platform's course can be changed. In such cases, the check is on whether the value of an attribute is legal or not; that is, have the constraints been satisfied? (See the logic of radar, remote, and Electronic Support Measures [ESM] track constraints and associated transactions in Appendix A). The next step would be either the development of a reasoning chain for analyzing the characteristics of the track (see the logic of correlation transactions in Appendix B) or the development of the reasoning chain for mission-planning actions.

This effort is a spinoff from research that D. Small of NOSC did in collaboration with Dr. Wesley Chu of UCLA in 1979 [Ref. 3] on expert systems processing for distributed database systems in the dynamic Navy C^2 environment, and from Dr. Lui Sha's (CMU) research in modular concurrent processing for real-time databases [Ref. 4]. There have been a number of articles on real-time systems, but in only a few instances has there been discussion on real-time database systems. The more notable of these include Dr. Roger King's (U. of Colorado) research in semantic query optimization and time management, using versions for relational databases [Ref. 5], Dr. Chu's work in optimal query processing for distributed database systems [Ref. 6], and Dr. M. Singhai's (University of Maryland) research in time stamping for real-time database management [Ref. 7].

The expert system processing model for distributed database systems [Ref. 3] and L. Sha's concurrent processing model [Ref. 4] will form a design basis for determining where the

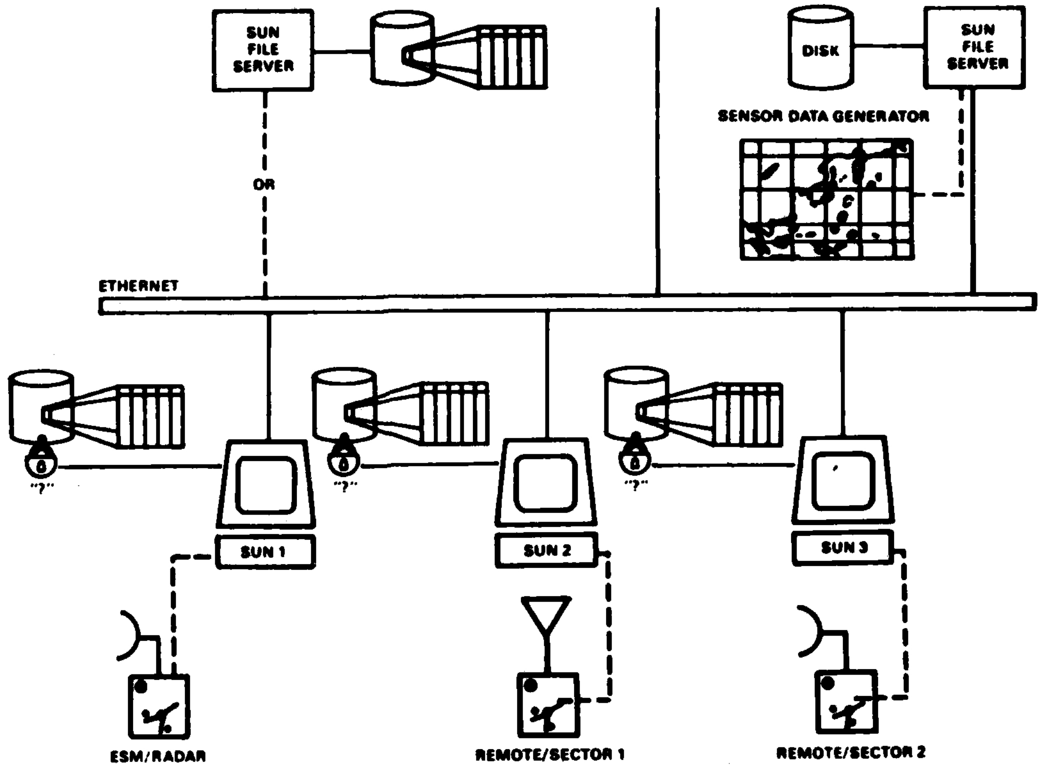

Figure 1. NOSC distributed tactical decision support tracking model testbed (using SUN processors).

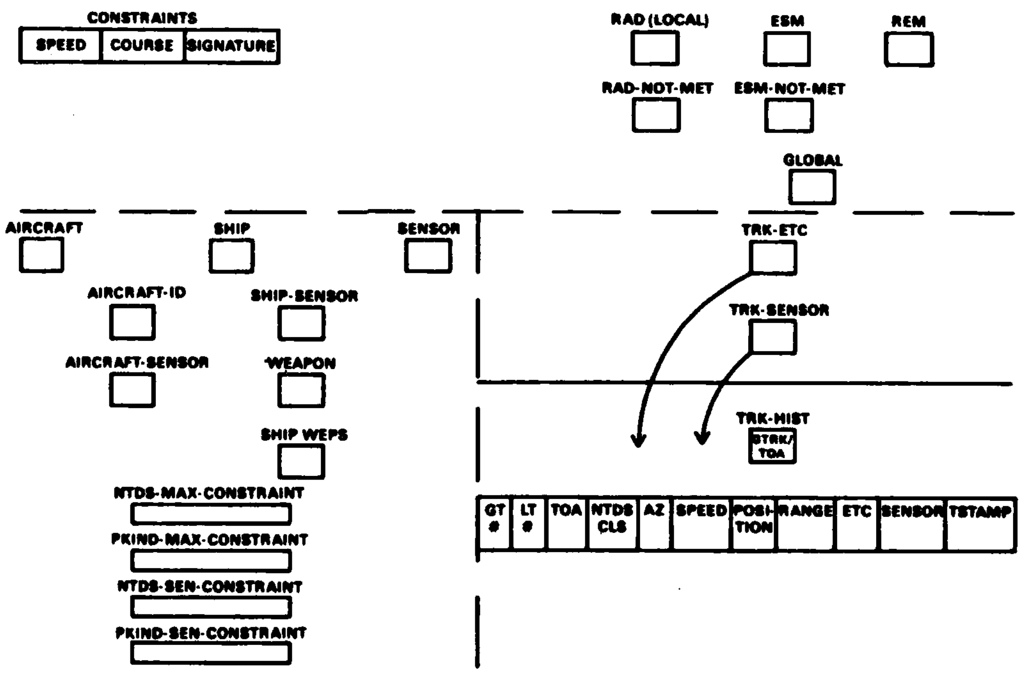

Figure 2. Distributed tactical decision support new track report logic database.

various knowledge elements reside. Based on this framework, legal values of the knowledge elements will be derived. By using such values, rules will be developed, for example, to determine the potential threat of a contact or target being tracked or to determine plans for weapon allocation. At any time in the analysis of a mission's progress—be it threat analysis, weapon allocation, or platform positioning—the distributed expert decision-making model will be able to recover dated information and install it, as appropriate, as current knowledge [Ref. 5 and 7]. Then it will unravel why any particular decision was made and assess the impact of that decision if it is followed to completion. The following sections of this paper will show, in considerably more detail, how various design alternatives using this approach are being pursued.

DISTRIBUTED TACTICAL DECISION-MAKING ANALYSIS ALTERNATIVES:

Distributed tactical decision-making alternatives being considered in this year's (1987) research are two-fold. (Other alternatives will be considered next year.) Figure 3 considers the alternative of track information being received from applicable Similar Source Integration (SSI) radar or ESM functions, or from remote tracks. This information is input at time = 0 to the centralized computer database resident in the Battle Force Track File (BFTF) database, as modeled in Figure 2. In parallel, track information is sent to the Dissimilar Source Integration (DSI) consoles by the CDS system according to operator needs. The operator's information may be sent according to doctrine as to what he should be monitoring, or according to the commanding officer's request for more information as he attempts to characterize a track as threatening or not. There is no concern in this alternative as to whether a track already has been integrated with other sources into a global track before more global track correlation processing is done.

Initially, consoles will be assigned global track correlation processing responsibility by console type, such as by radar, ESM, and remote sensor data source types; and for the contact types surface, subsurface, and aircraft, according to sector areas as shown in Figure 3. Rules are established as to when a console must communicate with other consoles. An example could be the ESM console's need to know more information about a track's position because of a sensor's indication that a track is likely hostile. An issue is how much of this type of communication is required in this alternative before the system's

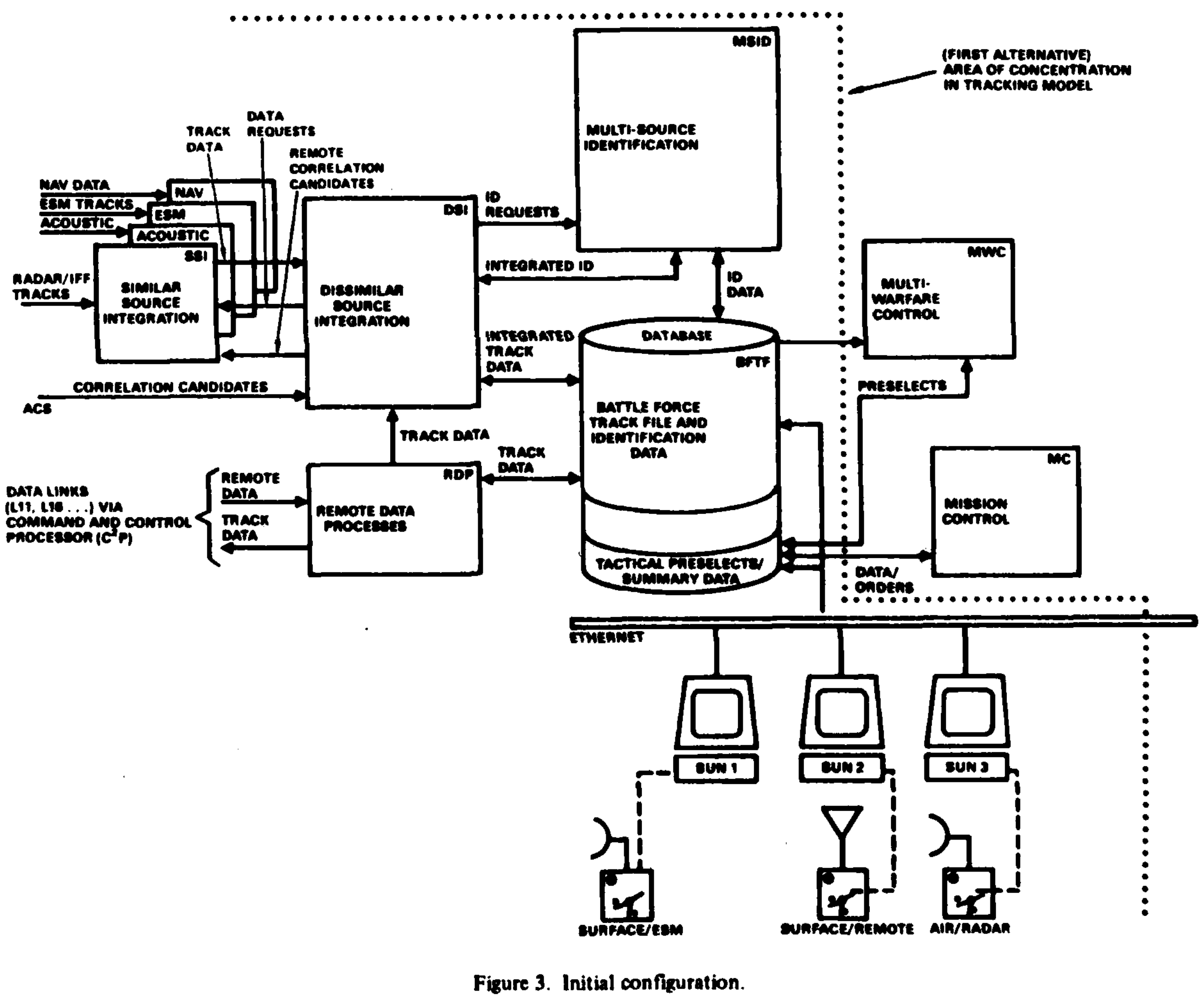

Figure 3. Initial configuration.

communication mechanisms become overloaded. Each console can be considered to be working serially and independently on its own set of tracks to determine their identification and location. There is no guarantee that the tracks are separate and distinct between consoles. Likewise there is no guarantee that a track being watched on one console was received at the same time by the CDS system as that same track being monitored at another console. An example of such serialized processing could consider each console as having a short track history, so that, when the operator receives a track report with an ellipse of uncertainty, he would attempt to match that track with his track history. He would assess the identification of the track based on evidence as to whether the track had its fire control on, or whether there was an indication of any other threatening maneuver such as an abrupt change of course and speed, or abrupt communication silence. Those track data will be kept internally consistent by maintaining the constraint rules described in the Theoretical Approach section of this paper. Serialized processing of the analysis (or global track correlation) of a track's location and identification (described in Appendix B) can be interrupted by the receipt of a new, "very important" track, such as a new track believed to be hostile, which MUST be included in the console's global database. In this instance, the ongoing analysis would be halted and rolled back to a recoverable start point.

A second alternative (see Figure 4) would be that of minimizing the global track processing by only doing correlation processing on new tracks or on those tracks which have radical changes. A new report arriving will be a candidate for a "global track" if its quality exceeds a certain confidence level threshold. Once it exceeds that threshold level, it either has established an association with other local level tracks via correlation or, vacuously, it is a global track if no association has yet been established. The model consists of two levels for this alternative, the local level (combining the local sensor level with the Similar Source Integration level) and the Dissimilar Source Integration (DSI) level. The local level has its own local track database and a global track database (global track numbers for local tracks). If a new report already has a global track number, and there are no significant changes, the local history will be updated and correlation will not be attempted at the DSI level. The DSI level consists of a Global Track database and "candidates" for a global track. If a "candidate" passes the correlation criteria, it is given a unique global track number that is propagated downwards to the local level (inserted in their global track databases). This alternative is described in more detail in working papers developed jointly by NOSC and Carnegie Mellon University in March 1987 [Ref. 8]. Its theory is based on the assumption that a track is an atomic data set (ADS) [Ref. 4], the smallest data unit that can

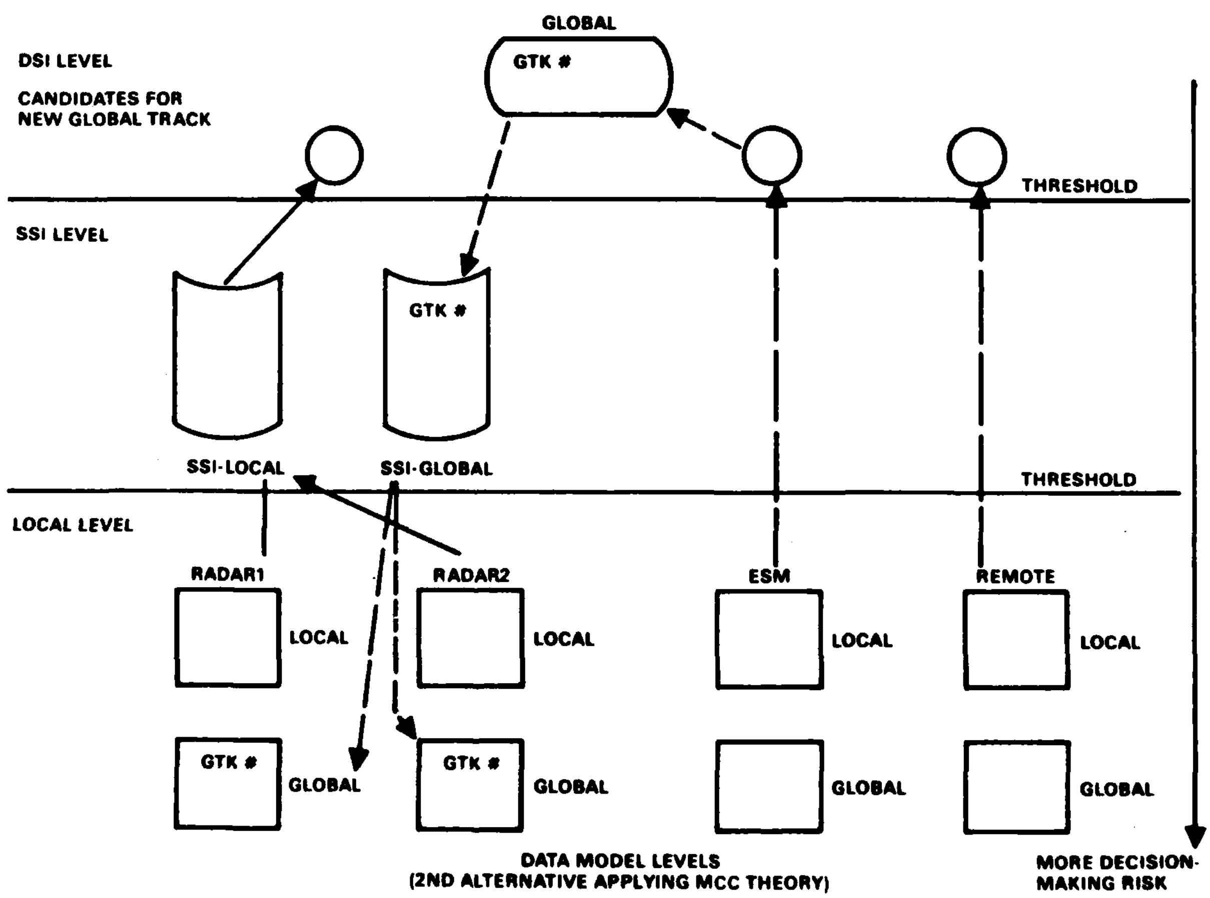

Figure 4. Distributed tactical decision support.

be synchronized. Elementary transactions [Ref. 4] on such ADSs include local constraint and association transactions and global track correlation (see Appendices A and B). In all cases the execution of these transactions must preserve the constraint or consistency rules established on entry of the track into the SSI/DSI processing levels to ensure correctness. For example, a track's correlation processing cannot be interrupted without preserving its state before the correlation started, therefore preserving the correctness of the transaction.

In both alternatives, a console's view of its tracks can be inconsistent from another console's view of those tracks. For example, in the first alternative, the air/radar console's view of an air contact's identification could indicate it to be friendly, whereas the ESM console's view of that same contact could see it as having an identification of hostile. These views can be consistent for a number of different reasons, while still obeying the constraint rules established when the consoles are operating independently. First, the console operator may receive new information on the track as it is broadcast from the centralized BFTF database. Second, a console operator may request help from the other console operators in identifying a track he feels to be hostile. Third, it could be that a console or group of consoles might become overloaded with responsibility for too many tracks, so that the responsibility would be shifted to less lightly loaded consoles, forcing data consistency to be resolved when the console locations are changed. The main computer also could change a console's responsibilities because of a change in perceived threat, such as noting a target in close proximity and assigning responsibility for that target to an appropriate console in a nearby sector. Or console operators, either by doctrine or by direction from the Tactical Action Office (TAO) and/or the commanding officer, are told they must report to him all hostile identifications within a preselected radius of ownship, forcing a consensus view of differing opinions.

In both alternatives, whenever a track is agreed to be hostile, the next step will be the sending of its value to the Multi-Warfare Control (MWC) and Mission Control (MC) building blocks of CDS. The MWC building block will support the action of weapon assignment and subsequent scheduling and engagement. This action would be based on threat evaluation data or weapon status, among other things. The MC building block supports the information needs of users in other systems supporting the battle group, which need a complete accurate assessment of the tactical situation. MC and MWC operator consoles will be modeled only as to time to assess the threat and validity of that assessment. Engagement will be considered the "death of a contact" and an end time will be assigned to that track.

COMBAT DIRECTION SYSTEM (CDS) OPERATOR CONSOLE CAPABILITIES:

Each DSI and SSI operator console will be provided automated capability for database management update, search, and analysis using the relational join and restrict functionality. Scheduling of those functions will be provided, as will the scheduling of requests of other consoles or of the main processor for information such as tracks within the radius of "x," hostiles in that radius, or changes in ID. All data used by the operator will be resident in the console processor's main memory or sent either on a predetermined basis or by operator request. Different profiles or contexts of expertise to be provided for the operator will be preselected for the console processor's memory, probably from the BFTF database. Appendices A and B are the first attempt at the modeling of such capabilities.

RELATIVE MEASUREMENTS FOR ANALYSIS OF ALTERNATIVES

A number of measurements have been alluded to in the Background and the Distributed Tactical Decision-Making Analysis Alternatives sections of this paper. In all cases, they evolve around the timeliness and quality of, and personnel involved in, the decisions made. In this paper, there is no attempt to go into details on the experimental design for gathering these measurements, but rather a first attempt to solidify the types of measurements to be gathered. In all cases, an attempt will be made to compare the approach of distributed tactical decision making with what today's centralized systems provide [Ref. 1].

Specifically, the measurements include the average time required for the operator to decide the threat potential for each report entering the system. The time required for a reversal of a decision can also be measured; for example, the time required to agree to a change in identification from hostile to friendly. The quality of data (i.e., number of decision errors over time) can be measured as well. For each decision, a determination will be made of how many operators are involved and the amount of communications required in the achievement of a consensus view of that decision. There will be an attempt to categorize these data by the type of decision made; for example, determination of radical change in a track's history, or change in identification. An assessment of risk for each alternative will be shown as a function of how much information was available to the decision maker at any given time.

At the engineering level of design for each console, a first-cut analysis will be made of how much information can reside reasonably at each level, based on processor size, speed, and available memory. Secondly, an analysis of processor bottlenecks will be considered, such as how much database locking must occur in a distributed database environment like the one discussed, and the effects on report analysis time.

OTHER EXPERIMENTAL ALTERNATIVES:

The results gathered from the research will be analyzed by using deliberate insertion of time-latent versions of track reports (track ADSs), based on Dr. Roger King's data object theory [Ref. 5] and Dr. M. Singhai's research in time stamping [Ref. 7]. That analysis, together with the tracking model alternative using Carnegie Mellon University's Modular Concurrency Control (MCC) theory, will aid in the application of MCC for the feeding of valid Combat Direction System (CDS) track data to information systems supporting the battle group. In the problem of mission control and planning, the next step will be the incorporation of resource allocation theory [Ref. 9] to help in the development of rules for the planning of platform deployment or weapon allocation (as examples). In all instances, relative performance measurements will be taken and performance analysis done and compared with the tracking problem described above.

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APPENDIX A

CONSTRAINT AND ASSOCIATION TRANSACTION LOGIC

```
{  pdl for radar local track  }

   if ( quality > 30% ) then
    calculate range,speed, and etc
    update tuple with range,speed, and etc
      if ( meets ntds_max constraints for ntd_class ) then
        if ( associated i.e. has glbl trk # ) then
    update local history
        end if
        if ( new report or significant changes) then
    { lock potential }
    correlate at global level {talk to ETC_GLOBAL_TRACK_TRANS}
        end if
    else
        append report to do_not_meet_rad_constraints file
    end if
end if


{   pdl for remote association    }

calculate range,speed, and etc
        if ( associated i.e. has glbl trk # ) then
            update local history
end if
if ( new report or significant changes) then
    { lock potential }
    correlate at global level {talk to ETC_GLOBAL_TRACK_TRANS}
end if


{    pdl for esm (electronic support measure) local track}

if ( quality > 30% ) then
      if ( meets esm constraints for platform_kind in
 pkind_sen_constraint
 and ntds_class in ntds_sen_constraints) then
        if ( associated {i.e. has glbl trk #} ) then
    update local history
        end if
        if ( new report or significant changes) then
    { lock potential }
     correlate at global level {talk to SENSOR_GLOBAL_TRACK_TRANS}
        end if
    else
        append report to do_not_meet_esm_constraints file
    end if
        end if
```

APPENDIX B

CORRELATION TRANSACTION LOGIC

```
{pdl for etc (estimated time of contact) global track correlation   }

if (outside of sector 1 and 2) then
    send track information to that sector's console
else
    if (  (report has significant changes and a global track number) or
  (quality < 90%) or ( track unknown) ) then
correlate
    else
case for track report
    quality >= 90 and confirmed friendly:
assign new global track number
send report back to local level
don't correlate
 { release lock potential - done below }
    quality >= 90 and confirmed hostile and (range too close or
      etc too soon):
repeat
until (request for verification from other
       operators is answered );
if ( agree ) then
    notify TAO and weapons control
    send track report information to weapon control
end if
send all information to local level
don't correlate
 { release lock potential - done below }
   otherwise : correlate
 end case
    end if

    if ( correlate ) then
       if ( report has global track number{gtn} ) then
    if ( report's id disagrees with its gtn's current id and
 quality >= 90%) then
delete gtn's history
resolve differences
    else
         if ( report's id disagrees with its gtn's history id ) then
    if ( quality >= 90% ) then
    delete gtn's history
    end if
    resolve differences
else
    don't resolve differences
 end if
    end if
 else
    resolve differences
end if
if ( resolve differences ) then
    repeat
get global track {gt}
if (platform kind of gt matches ) then
    if ( speed of gt is within constraint for report) then
if ( range and etc within limits for report) then
```

```
    if ( course whithin limits for report ) then
record gt number in list of possible matches
    end if
end if
    end if
end if
    until ( report is tested against all the global tracks)
            if ( more than one match ) then
repeat
    if ( history indicates radical range/etc/course
         change in track ) then
remove from list of possible matches
     end if
until( all possible matches processed )
    end if
    if ( more than one match ) then
call sensor global track correlation with new report
intersect its response(s) with our list of possible matches
    end if
    if ( one match ) then
change new global track number to the match's track number
insert/merge new report on/with match's history stack
{ release lock potential - done below }
    else
if ( no matches ) then
    request help from other operators
    if ( other operators identify the new report ) then
add new report as new track to etc global db
{ release lock potential - done below }
    else
use centralized system for correlation calculation
add new report as new track to etc global db
 { release lock potential - done below }
    end if
else { more than one match }
    put a copy of the new report on the history stack
        for each of the possible matches
    { release lock potential - done below }
end if { no matches }
    end if { match }
end if { resolve differences }
    end if { correlate }
end if { outside sectors 1 & 2 }

release lock potential
return results to local level


{pdl for  sensor  global track correlation  }

repeat
    repeat
if ( new track's sensors, id, and platform kind match the
     track being processed ) then
    add track to possible match list
end if
    until ( new report is tested against all the global tracks )
    if ( more than one match ) then
back up one point in time
    end
```

```
until (( one match ) or ( last data point reached ))

if ( one or more match ) then
    if ( new report is hostile ) then
        determine weapon with greatest range and speed for the platforms
          with the sensor of the new report
        call weapon sub-transaction
        { more processing of results of call - to be determined }
        send results of processing to etc global track transaction
    end if

    update the global db {used by both sensor and global trans. }
    { lock potential between sensor and etc global trans. if
      on different nodes }

    send information back to calling process
    { release lock potential }
else { no match }
    put copy of new report in global db
    send back to local level
end if


{  pdl for weapon sub-transaction  }

repeat
    calculate weapon etc to own ship
    repeat
if (current track and track in global db have approx. the same
    maximun range and weapon speed ) then
    add the track to possible match list
    until ( all tracks in global db have been checked )
until ( all track sent to this process checked)

return possible match list to sensor global track transaction
```

END
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